Evaluations of the hopping growth characteristics on 3-D nanostructure fabrication using focused-ion-beam

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Focused-ion-beam chemical-vapor-deposition (FIB-CVD) is a key technology to achieve the three-dimensional (3-D) nanostructure fabrication. FIB-CVD has several attractive features. 1) It is possible to fabricate arbitrary 3-D structures, such as wine glasses, bellows, and coils. 2) Various materials, such as diamond-like carbon (DLC), tungsten (W), and silicon oxide (SiO_x), can be deposited by changing the CVD gas source. Therefore, realizations of novel nano- and micro-devices with the 3-D structure were expected. However, evaluations of growth characteristics on FIB-CVD were not enough to achieve the 3-D structure with an arbitrary shape. Therefore we have been carrying out the clarification of growth mechanism on 3-D nano-structure growth.

In this study, the scanning speed dependencies of growth mode of carbon nanowire growth on Si substrate were evaluated, as shown in Figs 1(a) and (b). In this evaluation, carbon nanowires were fabricated by the analogue 1-pass scanning of 30 kV Ga FIB with a beam current of 3 pA. And we used *phenanthrene* ($C_{14}H_{10}$) as a gas source for carbon deposition. As a result, line structure was deposited on Si substrate at the scanning speed of over the 250 nm/s, and overhang structures were grown up by Ga^+ FIB scanning at the speed of less than 100 nm/s, as show in Fig. 1(a). And, growth angles of overhang structure were depended linearly on the scanning speed, as show in Fig. 1(b). These results indicate that the FIB-CVD has the two growth modes such as the line structure growth mode and overhang structure growth mode. In addition, we found that the arch nanostructure could be fabricated by FIB scanning of suitable speed (100 nm/s - 220 nm/s), as shown in Fig. 1(a). And, length of 1st arch structure was depended on the scanning speed, as show in Fig. 1(c). This result indicates that FIB-CVD have the hopping growth mode in addition to the overhang structure growth mode and line structure growth mode.

Furthermore, the applying voltage dependency of hopping growth was examined to understand the cause of the arch nanostructure growth. In this experiment, Ga FIB scanning was carried out during the applying voltage to the substrate, as shown in Fig. 2. Deposition rate of carbon did not change by applying voltage to the substrate. As a result, length of the 1st arch structure was depended on applying voltage as show in Fig. 2(b). This result implied that the hopping growth mode was caused by the electrical potential difference induced by residual charge in a growing structure and a substrate surface.

These results obtained in this study are very useful information to know the 3-D nanostructure growth mechanism. Growth characteristics of hopping growth mode on FIB-CVD will be reported in detail.

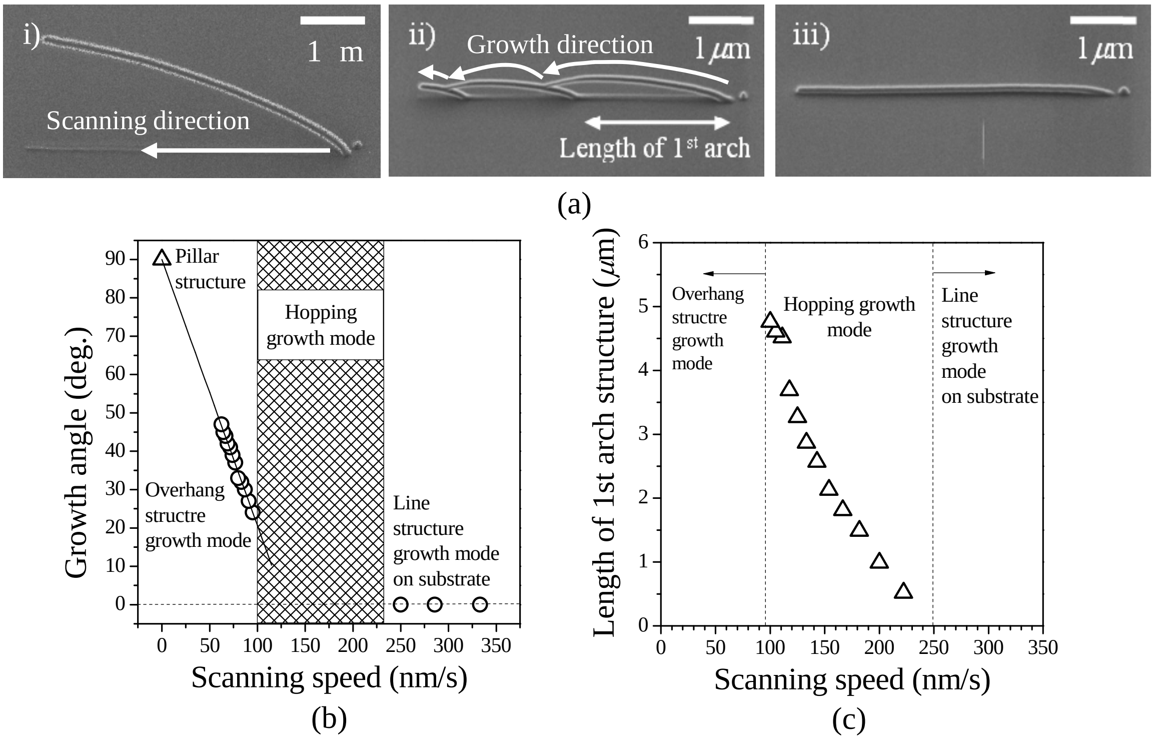

Fig. 1. Scanning speed dependency of growth mode on FIB-CVD;
(a) SIM images of nanowires fabricated by Ga^+ FIB scanning at the scanning speed of i) 83 nm/s, ii) 143 nm/s, iii) 250 nm/s, (b) Scanning speed dependency of growth angle, (c) Scanning speed dependency of the length of 1st arch structure on hopping growth mode

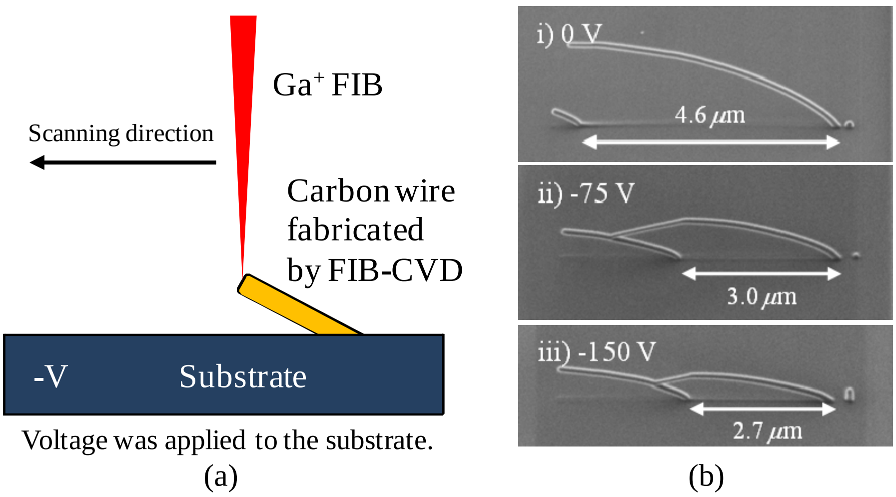

Fig. 2. Applying voltage dependency of the hopping growth;
(a) Schematic of the experiment, (b) SIM images of arch nanostructure fabricated by FIB scanning at the speed of 100nm/s. Voltage of i) 0 V, ii) -75 V and iii) -150 V were applied to the substrate during fabrication, respectively.